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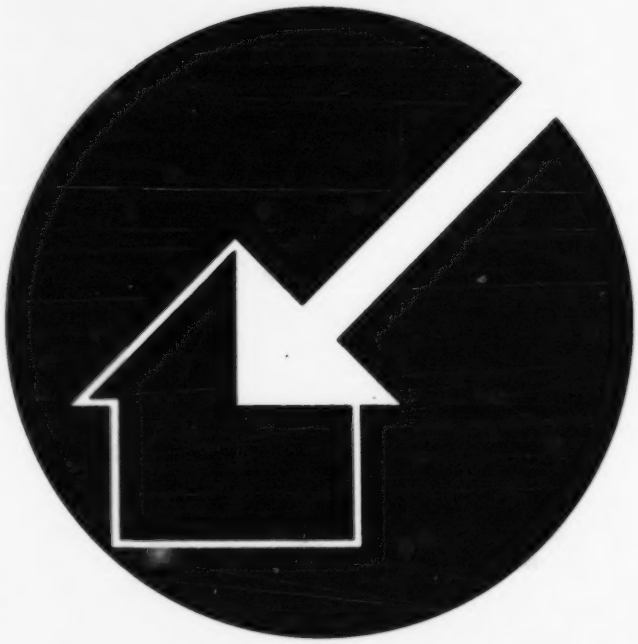
SEP Photovoltaics Program Review

May 1985



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by the
Photovoltaics Sub-Program
Solar Energy Program
Division of Energy
National Research Council

MAY 1985

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SEP Photovoltaics Program Review, May 1985

by the Photovoltaics Sub-Program
Solar Energy Program
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Abstract

This document is intended to give a historical perspective of the activities in photovoltaics research supervised by the Solar Energy Program. It covers the period 1977-1985. It explains the rationale of the decisions taken in the course of running the program. It summarizes the principal results of the program and the status of photovoltaic research in Canada as of May 1985.

Résumé

Ce document donne une perspective historique des activités du programme de recherche geré par le Programme "Énergie solaire". Il couvre la période 1977-1985. Il explique la rationale des décisions prises lors du fonctionnement du programme. Il donne un sommaire des principaux résultats et du statut des recherches en photovoltaiques au Canada en mai 1985.

SEP Photoltaics Program Review, May 1985

1. Sub-Program Evolution

1.1 Methodology

The National Research Council (NRC) took on prime responsibility for research on renewable energy in Canada in 1974, after the oil embargo had led to the formation of the Interdepartmental Committee on Energy Research and Development. Although most of the early NRC solar energy activity was performed in the Division of Building Research (DBR) on solar thermal aspects, and in-house work on photovoltaics (PV) did not exist, NRC had realized early that PV research should be encouraged. The first PV research contract, resulting from an Unsolicited Proposal (UP), and the first Request for Proposals (RFP) for PV work preceded the formation of the Solar Energy Project by almost a year. Appendix 1 gives a chronological history of RFP'S from this time to the present, and Appendix 2 lists the yearly funding levels.

The first two RFP's (in 1977 and 1978) were aimed at encouraging work in Canadian companies primarily on photovoltaic devices. Sixteen proposals were received in response to the first RFP with six contracts awarded whilst fourteen proposals came in response to the second with five contracts being awarded.

Since these responses indicated increasing interest and activity in PV, a project on PV markets in Canada was initiated in 1979. The work was carried out by Middleton Associates and the final report was published as NRC Solar Energy Program Report No. PV-1. With hindsight, the study is better viewed as an applications survey rather than a market survey as the projected cost reductions over a five-year time scale can now be seen to be unrealistic. Nevertheless, many applications were identified and cost-effective price ranges were determined.

As a further aspect of this work, Middleton Associates organized on behalf of NRC a seminar on PV1 in the fall of 1979 which was attended by representatives from government, research groups and users of PV systems. The general response to this seminar was enthusiastic. Several participating groups gave details of PV systems they were using or experimenting with. Further, they pointed out that the systems were not only dependable but cheaper than alternative power supplies for their applications.

By mid-1979, three Canadian companies - National Semiconductors Ltd. (now Silonex Inc.), Solar Cells Ltd., and TPK Inc.,- had begun to manufacture PV modules using imported silicon wafers. As a result of all this evidence of increasing PV activity in Canada, the Division of Electrical Engineering at NRC created in effect a "PV mini-group" in the Electronics Engineering Section. The Solar Energy Project (SEP) purchased 25 Canadian-made modules for evaluation by the mini-group. Also, at this time, an RFP was issued for work on small PV systems leading to three contracts by early 1981.

In the autumn of 1980, a review of the entire NRC Solar Energy Program was undertaken with contractor assistance[2]. Part of this exercise was to lay out, by tasks, funding levels needed for a five-year period. The format used was a many-element matrix of tasks/activities against use (or systems/applications) with the matrix entries showing total funding over the 5-year period. This format tended to overemphasize funding required and did not display program evolution over the time period. Therefore a simpler format was developed with a matrix of tasks against financial years. The first version of this matrix is shown in Appendix 3. With only minor variations, the same groupings are still in use.

At this time an SEP Advisory Committee on PV was created to perform a technical 'peer review' of the SEP's PV programme. The Federal Government's emphasis on solar thermal R&D had resulted in the existing NRC Associate Committee on Solar Energy having a membership unsuitable for this PV review task. The PV Committee's mandate and membership were chosen to make it an independent entity. The funding levels, given in Appendix 3, were approved by the PV Committee at its first meeting on November 26, 1980. In the Committee's view, the table entries represented the levels of expenditure on PV topics required and feasible in the Canadian context. However, two shortcomings of that table were recognized: it did not consider

i) the in-house R&D activity necessary to support, or
ii) the manpower needed to administer

a program of such a size and complexity.

In the same meeting, objectives for the PV Sub-program were set refining those given in an earlier document[3] for all aspects of solar energy. The main objective of the program was to encourage the development of a viable Canadian PV industry, able to capture part of the market in Canada and elsewhere. In support of this objective, it was realized that not only were research contracts with industry needed, but also support projects on test methods, standards, and studies on use of systems in the Canadian environment. By helping to establish a Canadian industry as well as understanding how to design PV systems for use in Canada, it was expected that PV in the long term would make a contribution to Canada's energy supply.

In the "Solar Energy Review and R&D Plan for 1981/82 - 1985/86"[4], similar objectives and recommended budgets were given for the Photovoltaics Sub-program. This document also included estimates of manpower needed in SEP, rectifying the omission of the November 26, 1980 meeting.

1.2 Devices

In early 1980, a third RFP on PV device R&D was announced. At this time it was apparent from PV R&D in other countries that amorphous silicon (a-Si) was an extremely interesting candidate to be the basis of the very cheap thin film solar cell of the future. However, most Canadian research activities on a-Si were in universities, not in industry. This RFP therefore attempted to solicit proposals from companies interested in PV devices willing to subcontract to university research groups. Because the expected SEP PV funding level was inadequate for several independent contracts of sufficient size, a coordinated effort was requested with one company overseeing the work of several research groups as well as making its own contribution. Unfortunately this apparently reasonable approach failed. The experience showed that it was

a) unreasonable to expect research groups to band together voluntarily as they are by nature somewhat competitive;
b) unwise to restrict the program to R&D aimed at early products;
c) unwise to a priori exclude the possibility of placing contracts directly with universities and non-profit organizations.

Canada does not have a strong industrial research base on such topics as thin film semiconductors. Much of the expertise is found in the universities. Therefore, the restriction of letting contracts only to companies tended to create artificial alliances where a company was, in effect, used as a "front". This led to extra costs and one more level inserted between the NRC personnel responsible for the research and the technical people carrying out the work. In spite of these problems, a contract was eventually let with sufficiently encouraging results to lead to follow-on work; but the original goal of the RFP, a Canadian a-Si effort with a company standing by ready to take the results to commercialization, was not achieved.

The lessons learned from this a-Si RFP subsequently led to the issuing of the first of the "Newer Materials and Devices for Conversion of Sunlight to Electricity" series of RFP's. This RFP reverted to the form of the first RFP's of 1977 and 1978 issued on PV devices. Basically the concept was "give us your best ideas for work and they will be ranked in order of technical merit". Then, taking into account the need for the SEP PV programme to keep in balance with the current world scene, the SEP would fund technically good work within the planned framework. Universities and non-profit organizations were not excluded from making submissions themselves but they were encouraged to find industrial partners. However, the wording of the RFP was carefully chosen to avoid encouraging them to do so artificially. The previously implied restriction of short-term payback in products was also removed. The RFP was intentionally kept very general to permit building on existing expertise in the scientific community.

The response to this RFP was very satisfactory to those involved in its planning. Some 14 proposals were received and three contracts placed, two of the three in fact with companies. Furthermore, the cut-off at three was predominantly a result of budgetary restrictions, although it also reflected the fact that a number of groups were still working on contracts resulting from earlier RFP's.

The Newer Materials RFP was issued a second time nine months later with equally satisfactory results. Five contracts were placed, two of which were effectively follow-on work from the earlier RFP on a-Si.

The third Newer Materials RFP, issued in April 1983, differed from the first two only in that it emphasized work on thin film devices based on materials other than a-Si as three large a-Si contracts were in place at that time. This RFP led to five contracts, all with companies, and included work on CdTe, $CuInSe_2$ and tandem junction cells.

A more complete range of topics, as measured by activities and achievements worldwide, was now covered with a better utilization of Canadian research expertise. The work was becoming more directed, more 'mission-oriented', and it was anticipated that future issues of the RFP would have priority topics more closely defined. The increase in technical manpower in the SEP also permitted a closer monitoring of these highly specialized projects.

One major problem, which was now becoming increasingly serious, was that the research groups were severely undercapitalized. They lacked vital equipment and had no source of money to buy it. PV device R&D activity is sophisticated, high technology, and rapidly evolving, which inevitably means that expensive equipment is needed to maintain research of world class level. Most of the required capital items were highly specialized and could not reasonably be deliverable items after a contract. A solution to this problem had to be found if competence in this area of research was to continue and to approach a level competitive with other countries involved in PV work.

1.3 Module Development

As already noted, three Canadian companies had the capability of manufacturing PV modules as early as 1980. From that time on, SEP has been supporting a series of applied projects with all three companies.

The SEP policy was that work in this area should only be supported if

a) the proposing company was actually manufacturing and selling modules or would be able to do so in the immediate future, or
b) the proposal was accompanied by strong support from at least one company of the type described in a).

1.4 Systems

The first systems RFP, issued in early 1980, had led to three contracts with some promising results. However, a second systems RFP issued late in 1981 was not as successful. Four proposals were selected but only one led to a contract. Of the other three, two were eventually dropped because the expected involvement of other agencies or groups in the implied field trials never evolved into firm commitments. These failures appeared to be due to

a) the small size of the companies and thus their inability to bring leverage to bear;
b) the lack of any Canadian policy beyond NRC for encouraging PV activities.

Generally, the response to the systems RFP's was less satisfactory than that to the newer materials series. The topic is more applied and therefore needs industrial work. Problems are of shorter term; some PV systems are cost-effective now. The SEP's main purpose at that point was to develop systems design expertise in Canadian companies. It was not intended to totally fund system development projects with short term payback. Some of the projects supported in this learning phase, however , had the potential to lead to systems with a defined market, which was seen as an added benefit, because companies with marketable products had a chance to become more competitive and less dependent on government programs.

The utilization of PV electricity for a very broad range of purposes resulted in a fragmented approach. Even when the proposed system application was well defined, few proposers could adequately address all the related problems, or involve suitable subcontractors. Many proposals seemed to come from what one might call PV enthusiasts - i.e. groups which believe PV is very important but which for various reasons could not yet produce an adequate technical proposal. Most of the submitted proposals displayed one or more of the following shortcomings:

a) a failure to take into account all the disciplines required;
b) failure to identify a company with the capability to eventually take over production of a polished and competitive product;
c) inability to involve other agencies adequately in field trials, testing or certification.

It should be noted that the roles envisaged for PV applications makes it imperative that the systems are very reliable - e.g. for warning/safety lights, scientific data collection, or communication networks.

These experiences confirmed the view that the topic of systems/field trials required more direction from NRC as well as a commitment from other government agencies to participate. Furthermore, there was a heavy demand on SEP staff to steer projects in useful directions and to provide back-up technical expertise in the areas where project groups were weak.

1.5 Standards for testing modules and systems

a) Standards

PV standards activities in Canada commenced in early 1981 with the creation of two Canadian Standards Association (CSA) PV Working Groups, one on modules and the other on storage batteries. The module working group has now become a CSA Committee. In 1982, this committee produced a draft Canadian standard for PV modules and then in October 1984, a preliminary standard. The storage battery working group is presently inactive. However, a further working group was created in 1982 and was attempting to produce guidelines on PV power conditioning units. NRC has sent representatives to all these committees and working groups from the start of their activities. Other representation comes from the PV modules sales and manufacturing industries, suppliers of components, systems installers, user groups, other government agencies and universities.

b) Test Methods

The increasing use of PV in Canada led to the need for Canadian component testing. This need was emphasized by the production of the CSA draft standard and test specifications for modules by larger users. As NRC had already built the National Solar Test Facility (NSTF) for active solar collector testing in Mississauga, operated by the Ontario Research Foundation (ORF), a contract was let to ORF to evaluate its suitability for PV module testing and to make recommendations on PV test methodology. Additionally, within the contract ORF was authorized to acquire or build the preliminary equipment necessary to determine I-V characteristics under standard conditions.

At this time ORF, by utilizing the NSTF as well as their own environmental test capabilities, is able to test PV modules to users' specifications or to the majority of the tests in the draft Canadian standard. The testing of the first SEP block purchase of 5 sets of pairs of modules was completed in the fall of 1983.

1.6 Ontario Hydro PV System at Atikokan

At the 1979 NRC PV seminar, already mentioned in 1.1, it became apparent that several Canadian government agencies were experimenting with PV power systems for special applications. Furthermore, by early 1980 three Canadian companies had announced that they could manufacture modules. Thus, at that time, a proposal from Ontario Hydro for a PV system field trial was particularly opportune as it offered a chance to gain field experience in the Canadian environment and to field test Canadian made modules. The proposal was to install a system powering an SO_2 pollution monitor near Atikokan, Ontario. Atikokan was to have a coal fired generating station installed in about three years time, and Ontario Hydro's policy was to monitor SO_2 levels for several years before and after such installations to determine the effect on acid rain levels. Sites had been selected for six such monitors near power lines but calculations had shown that a seventh was needed at a point with no electrical power nearby. Since standard diesel generating sets could not be used because of the combustion products, and a power line extension would be costly, Ontario Hydro proposed to combine their need for power at the site with their desire to experiment with PV power for remote Canadian locations, and to install a PV array at Atikokan.

After lengthy discussions, NRC and Ontario Hydro agreed to go ahead jointly with the project with costs shared on a 50-50 basis. In addition to installing the system itself, Ontario Hydro would install equipment to monitor the system's performance and report on this for five years. The final photovoltaic array design consisted of three sub-arrays; one from each of three Canadian companies, Silonex, Solar Cells Ltd. and TPK. The total array power was to be 2400 watts peak, approximately one-third being supplied by each manufacturer.

While all involved with the project agree that many mistakes were made along the way, they agree as well that numerous valuable lessons were learned. Initially, the main concern was whether the Canadian made modules would perform satisfactorily. In fact, after some initial problems with 12 modules, no module failures have yet been detected.

Recent measurements by Ontario Hydro did show that two of the sub-arrays have degraded in power output from that originally measured and that the I-V curves of all three have poor fill factors. Unfortunately, it is not possible to trace the causes of these shortcomings since

a) no measurements were taken on the modules before installation nor on the arrays immediately after installation;
b) no provision was made for measuring individual modules to determine whether uniform degradation or increased mismatch was the cause of the reduced power and poor fill factors.

Design and installation phases brought forth a series of problems and mistakes: a not unexpected situation as no-one in Canada had any experience with such a system at that time. With hindsight, these problems showed that it had been unwise to place one's first experimental system in a remote location. Engineers had to be brought in from Ottawa and Toronto and in winter, the system could only be reached by snowmobile. The Ontario Hydro reports[5] document the problems encountered and the down time of the system.

Until 1984, the Atikokan system was the only one in Canada being monitored; and it was anticipated that performance data could be analyzed to improve design. However, the parameters recorded were not sufficient, or they were not recorded with sufficient accuracy, to achieve this goal. Further data on component performance as a function of such parameters as temperature (of the battery as well as of the PV modules), insolation, and snow cover, to determine the variation of the system efficiency with time were missing.

Nevertheless, the data collected do assist Ontario Hydro in determining the overall performance of the system and the causes of problems. It is of interest to note that their overall conclusion, to April 1984, was that the PV modules were the most reliable part of the system. Moreover, the lessons learnt at Atikokan have been important in the design of NRC's program of system performance evaluation, discussed later in Section 2.

1.7 Technical Links with other Divisions of NRC

At the beginning, the NRC PV sub-program was managed by one professional working part time in the Energy Project Office, and all research projects were contracted out. As the sub-program evolved and expanded, more personnel were added; groups in other NRC divisions began to work on PV related topics; and, eventually, the Division of Energy began to establish its own in-house research capability.

In 1978, a link with the group in the Chemical Physics section of the Division of Chemistry, which worked on thin film semiconductors, was established. A scientist was hired by the Energy Division to work part-time on PV sub-program activities and part-time on PV-related research topics in the Chemistry Division laboratories. While the increased work load in the PV sub-program necessitated the research officer reverting to being full-time in the Energy Division in 1980, the link with Chemistry has continued. Scientists from the thin-film semiconductors group regularly participate in proposal review and technical monitoring of contracts related to their specific expertise. It should be noted that this group did not work on photovoltaics per se but on the larger topic of thin-film semiconductors of interest to the micro-electronics industry. Their advice was extremely important in this highly technical, rapidly advancing field.

At about the same time, links were established with another group in the Division of Chemistry, responsible for the program on Energy Storage, Conversion and Hydrogen Systems. This group was concerned with research on batteries and other means of electrical storage, fuel cells and hydrogen as a fuel, all of which were topics of importance to photovoltaic systems. This particular link was strengthened when the group became part of the Division of Energy in 1981.

Since the inception of the Energy Project, the PV sub-program personnel, because of their particular scientific background, have had a responsibility of solar resource assessment work, an activity tasked to the Atmospheric Environment Services (AES) of Environment Canada. Because of this responsibility, links were established with the Optics section of the Division of Physics on projects of mutual interest: spectral measurements of solar radiation, calibration of solar simulators, and spectral response measurements of photovoltaic cells.

In late 1979, on the initiative of the Energy Project, another link was established, this one with the Division of Electrical Engineering. A mini-group of two officers was formed in the Electronic Engineering section of that Division to work on photovoltaic related topics. Initially they set out to monitor PV module performance, purchasing the first 25 Canadian-made modules for this purpose. Later they expanded their activities to include system design and component studies. In 1984, a consolidation of these in-house activities, in the Division of Electrical Engineering and the modelling and performance evaluation work initiated in the Division of Energy itself, took place, as will be discussed further in Section 2.

1.8 Links with other agencies and funding programs

Links with other government funding programs were developed to avoid duplication of effort and to define the areas where the directed research program of the Division of Energy was most needed. Within NRC, the important interaction is with the Industrial Research Assistance Program (IRAP). Proposed projects were frequently discussed with both the IRAP officers and scientists from other Divisions who advised IRAP.

The National Science and Engineering Research Council (NSERC) Strategic Grants Program has supported many PV projects, primarily on thin-film device work. The PV sub-program staff was asked to review project proposals for NSERC and to participate in their site visits. Through the review process, the SEP staff tried to keep NSERC and its committees informed about NRC's PV program and the relevance of their university projects.

The Department of Regional Industrial Expansion (DRIE), Energy, Mines and Resources Canada (EMR), the Ontario Ministry of Energy, the British Columbia Research Council, and the Formation de chercheurs et action concertée (FCAC) of Québec, as well as the Unsolicited Proposals Program of Supply and Services Canada (SSC), have all asked the PV sub-program staff to review proposals for them and so assist in their selection processes. Contacts with these programs were maintained by the PV sub-program to ensure that it was aware of other government funded projects on photovoltaics.

More recently, links of a different nature have been established with further government programs where the government agencies were users of PV systems, rather than sources of funds for contract research and development. Here the role of the PV sub-program staff has been that of an active participant rather than that of a passive advisor. The Atikokan project (see Section 1.6) can be considered as the forerunner of this type of interaction. The current activities of this type will be described in Section 2 under the heading "Performance Evaluation".

2. Sub-Program Status

2.1 Introduction

The program has continued to grow as Canadian companies developed their expertise and new activities became possible. The "matrix" of activities has also evolved to reflect the changes in emphasis (see Table "1").

This section is organized according to the activities of column 2, as this matches fairly well with similar activity lists for the other solar subprograms, and with that used by the SEP Scientific and Technical Information Office in their Contract Registry.

However, in the last year, a new grouping (shown in column 3) began to be used - for example, in the "Green Sheets", the submission to the Panel on Energy R&D (PERD).

This consolidated grouping of column 3 reflects the major thrusts of the program at this time:

I) materials and device research
II) module and cell processing technology
III) system development and performance evaluation

TABLE "1"

1	2	3
A) Long-term R&D	A) Materials/devices	I
B) Short-term R&D	B) Module/Cell processing technology	II
C) Components	C) Components/Systems development	III
D) Systems	D) Performance evaluation	III
E) Testing & standards	E) Testing and standards	II
F) Other	F) Feasibility & Information Studies	III

Column 1 - Original topics of 1980
Column 2 - Topics currently used for planning purposes
Column 3 - "Main thrusts" grouping (See text, Section 2.1)

This division in three main groups of activities is convenient, as it matches fairly closely the budgetary split for the past three years, and what was foreseen for the near term future, i.e. approximately one third of the available funding on each. More importantly, the work of the sub-program breaks down logically into these groups in terms of time scale for payback, and furthermore, the prime performers are different in each group. However, the division cannot be viewed too rigorously: for example, projects on device research in their later stages would become classed as cell/module technology, and systems performance evaluation includes the field performance of new generations of PV modules.

Group I is dominated by large university-based research groups, often linked closely with industry to ensure a practical approach. The time scale for payback (in the sense of commercial products) for activities in this Group is five to twenty years, but evaluation of the prospects of individual projects would typically occur within three years.

Group II activities are shorter term with a payback expected to occur in five years or less. The prime performers are companies manufacturing or about to manufacture PV modules or cells. Most of the sub-program's testing work has also been included in this group as it is primarily directed towards accelerated lifetime testing. This work is concentrated at the NRC National Solar Test Facility (NSTF) at the Ontario Research Foundation (ORF). Standards development activities, an insignificant item in budgetary terms in which NRC staff and industry representatives participated and which was primarily directed towards module performance, was contained within this Group. Most of the other system components were already covered by existing test methods and standards. Any evaluation or testing of components other than the modules was included in Group III as part of System Performance Evaluation. The "standards" activities in these other areas were more directed towards the writing of guidelines and handbooks.

Group III activities include component and system development projects which are usually completed in one or two years and done overwhelmingly by industry. However, these projects then may be followed by a longer performance evaluation phase. The prime actor in the performance evaluation projects would have been NRC itself with significant assistance from other government agencies, both federal and provincial, and contractors in industry and universities.

Battery research and development, while potentially very important for photovoltaics in the future, was not funded by this sub-program as it fell within the mandate of a different task of the PERD Program (Program 1.8 - Energy Storage, Conversion and Hydrogen Systems). However, use of "state-of-the-art" batteries as part of a PV system was being studied within the Performance Evaluation sector of Group III.

For planning purposes - to permit flexibility and to match more closely the other Solar Energy sub-programs - the activities list of Column 2 of Table "1" was maintained.

Appendix 4 gives the detailed budget estimates, by topic, proposed in late 1984 for FY 1985/86. These numbers are based on what was considered feasible in the Canadian context; i.e. taking into account industrial and university interests and capabilities, as well as NRC manpower on PV. These numbers can be compared to those in Appendix 3 for FY 85/86 to see how well the 1980 projection matched that of 4 years later. It will be seen that the major difference is in topic B, cell and module processing technologies, where the 1984 estimate is much lower than that recommended earlier. This difference results in part from an overestimate of how rapidly the Canadian industry could evolve to compete with industry assisted by far larger programs in other countries. Work on this topic had, however, been growing, and TPK Solar, in particular, had reported success in competing on the world market. Additionally, however, some work related to cell and module processing technologies is classified in this table as part of topics D or E (testing of modules or performance evaluation).

The following sections attempt to give a "snap-shot" of the status of NRC's PV research program as of November 1984.

Short descriptions of the contract projects are given in the July 1984 edition of the SEP "Contract Registry".[6] Earlier projects can be found in the Contract Registries of July 1982 and July 1983[7], or in the Contract Directory[8]. Final reports from most contracts are available from the Canadian Institute for Scientific and Technical Information (CISTI), Ottawa.

2.2 Materials/Device Research

While all aspects of PV technology continue to evolve, as higher efficiencies and lower costs compatible with the maintenance of reliability are sought, by far the largest potential gains are in the fabrication of the solar cell itself. This situation is reflected in the large fraction of the PV R&D budget devoted to thin-film devices in all major countries. Such work includes research on 'newer' materials (i.e. other than crystalline silicon), on thin-film deposition technologies, and on different device structures.

The first NRC project on this topic, as mentioned in Section 1, resulted from an Unsolicited Proposal received in 1976, and contract research continued to grow from that time. For the last three years, about 30-40% of the PV budget has been devoted to thin-film materials and device work, all contracted out, and arising from winning proposals in response to RFPs. In FY 84/85, the total value of such contracts amounted to almost $1M.

This type of work requires large, well-equipped teams of researchers with an on-going research activity in thin-film physics. Projects often need several years' work before they can be assessed as to their industrial potential. Access to very expensive film deposition and characterization equipment is essential and few Canadian companies have such facilities. Therefore, projects often included large subcontracts to university semiconductor physics groups, or were placed directly with university groups.

Projects have ranged over a number of different materials including amorphous silicon, CdTe and $CuInSe_2$; several deposition technologies such as spray pyrolysis, glow discharge, electrodeposition, screen printing and thermal and electron beam evaporation; and a variety of device structures such as homojunctions, heterojunctions, Schottky barriers, p-i-n junctions, and tandem junctions.

Recent projects are described in more detail in reference [9], in the paper entitled "NRC's R&D Program on Photovoltaic Materials and Devices".

A new topic, that of luminescent concentrators, was being added in 1984. Luminescent concentrators are transparent plates containing a dispersion of molecules which absorb solar radiation and re-emit it. The re-emitted radiation is trapped in the plate by internal reflection, and can be collected at an edge, for example by photovoltaic cells. Although luminescent concentrators are not PV devices, the close similarity of research on them in terms of technical sophistication and type of contractor makes it appropriate to discuss the topic in this section rather than as systems components.

Luminescent concentrators are of particular interest to the sub-program because of

i) their wide acceptance angle for light (i.e. the higher diffuse component of the solar radiation in Canada by comparison with locations at lower latitudes is not a disadvantage;

ii) their avoidance of expensive (and less reliable in comparison with PV modules) sun-tracking mechanisms;

iii) their synergism with photovoltaics caused by the possiblity of designing them to optimize the wavelength range for maximum conversion to electricity and minimum conversion to heat (which reduces PV performance).

While several luminescent concentrator projects were under negotiation, none had led to a contract prior to November 8 1984.

2.3 Cell and Module Processing Technology

For some four years, several Canadian companies have had the capability of manufacturing PV modules including the fabrication of PV cells from single crystal silicon wafers, the interconnection of the cells, the encapsulation and the framing.

However, these modules have not been considered fully qualified by users as they have not passed accelerated lifetime tests nor been field-trials over long periods of time by an independent agency. Furthermore, in most cases they could not compete in cost with foreign made modules at present. All these Canadian manufacturers run the risk of not achieving competitiveness in the future as the cost of foreign modules continues to drop as the result of major research, development and demonstration programs.

The NRC PV sub-program has supported the Canadian PV module manufacturing industry in a number of ways:

i) development of a module testing facility to perform accelerated lifetime tests (see Section 2.6);

ii) participation in the writing of module standards (see Section 2.6);

iii) field trials of Canadian modules (see Sections 1.6 and 1.7 for early work). A field trial of statistically significant numbers of Canadian made modules was being planned as part of an in-house project which will be described in Section 2.5.

iv) direct support by R&D contracts to companies making cells and modules in Canada.

Solar Cells Ltd., of Burlington, Ontario, in a series of projects, investigated the production of large area cells on both monocrystalline and polycrystalline silicon substrates using the technique of spray pyrolysis to deposit transparent conducting oxide layers. This work permitted the company to develop a cell manufacturing process inherently cheaper than the standard one since it involves far fewer processing steps. The active junction is formed with the spray-on oxide coatings and the electrical contacts are screen-printed. Average efficiencies of 14%, in a production mode, were reported by Solar Cells Ltd. in a paper presented at the 17th IEEE Photovoltaic Specialists Conference (p.569 of the Proceedings) in May 1984 at Orlando, Florida.

TPK Solar Ltd., of Nepean, Ontario, developed a method of fabricating low-cost solar-cell grade substrates directly from metallurgical grade silicon. A fast three-step leaching process was used to upgrade the metallurgical silicon. The refined powder was then spread on a reusable graphite substrate and subjected to two scans with an electron beam. The first low-power scan sinters the powder while the second scan, at higher power, causes a molten zone to move across the sample leaving in its wake a smooth flat polycrystalline substrate. This work was also the subject of a paper at the 17th IEEE PV Specialists Conference (p.1382 of the proceedings).

Silonex Inc., of Montréal, Québec, carried out a project involving work on both cell processing and module manufacturing technologies. The cell processing studies concentrated on using plasma etching techniques

1) to eliminate wet chemistry processes for pre-diffusion cleaning and photoresist stripping,

and ii) to replace sand blasting and grinding for removing the diffused layer on the back and edges of the cell.

The plasma-etching approaches are much superior to the standard techniques in terms of use of manpower. On the module side, a new design of extruded aluminum framing with better corrosion resistance and shock protection was developed. This new framing was incorporated into the module production along with the introduction of lamination for encapsulating the cells.

In the summer of 1984, two new projects were under consideration, which aimed at increasing module efficiency and reliability while reducing manufacturing costs. These had not yet led to contracts at the time of the November 1984 cuts.

2.4 Systems and Component Development

The development of a design and construction capability for PV systems is clearly essential for the survival of the Canadian PV industry. The number of systems installed in Canada continues to grow (for example, a 1982 survey listed more than a thousand), and the market in developing countries is very large. Many requests to companies are for quotations to install complete systems as opposed to requests for delivery of modules only.

As mentioned in Section 1, the initial approach was to solicit ideas for projects through a general RFP similar to that used successfully for PV device work. While the first two RFPs on small PV Power Systems did help to identify many interested groups, and some successful projects on component development were carried out (see SEP Contract Registry 1983), the results overall were disappointing. Companies were either too small, or the range of technical disciplines needed were too large. Groups knowledgeable on photovoltaics often lacked other necessary engineering expertise, while groups with broad engineering background were unfamiliar with photovoltaics or its applications.

In 1983, therefore, a new and more directed RFP was issued. It highlighted a specific topic: photovoltaic-powered water pumping systems. Market projections indicated that these would be the basis of the next major PV sales thrust. Although these water pumping systems were not important in the Canadian market or for Canadian energy supply, they could be a significant product for export. Further, since such systems combine such widely disparate components as mechanical pumps and electric motors with photovoltaic modules and control electronics, and since that must be designed for simplicity and high reliability, a company that could build them successfully should be able to readily develop systems for other purposes as well.

This RFP, by highlighting a particular topic, was able to be more specific than previous ones on the type of projects sought and on suitable groups to undertake them. Emphasis was placed on the formation of teams to include expertise on components such as pumps and motors as well as on the photovoltaic module performance and electronic controls. Guidelines were given on the types of projects expected, for instance, phased proposals separating design, development, laboratory testing and field trials. Proposals outside of the priority topic were not excluded: a) stand alone systems for a specific other purpose, b) specialized system components and c) studies of systems for use in the Canadian environment, were suggested in the RFP.

This directed RFP turned out to be a successful approach. Many well thought out proposals were received and eight contracts were awarded. Of these, four were on PV-powered water pumping and money was earmarked in these contracts for travel and other liaison between the four groups. A workshop on the topic was held in February 1984, and was attended by representatives of the four contractors and other interested groups. A second one was planned for early 1985.

Peter Ward and Associates received a contract to develop a deep-well PV-powered pumping system based on a pump type already in common use in Africa. TPK Solar were to develop a shallow-well pump optimizing the design of a system utilizing a centrifugal pump which matched the PV-motor combination fairly well. A group of the University of Waterloo, with extensive experience on Active Solar system simulation, were awarded a contract to develop a PV water pump simulation model. The Ontario Research Foundation were to develop a PV water pumping system test facility, drawing through a subcontract on the experience of Sir William Halcrow and Partners in earlier UNDP/World Bank projects.

After the awarding of these contracts, the Canadian International Development Agency (CIDA) has announced a major project on photovoltaic water pumping systems targeted for the Sahel region of Africa. The projects sponsored by NRC should give Canadian industry a head start in responding to CIDA's requests for systems.

Four other contracts were also awarded as a result of this RFP. Bowie Keefer and Associates teamed up with TPK Solar Systems on a winning proposal to develop a PV-powered reverse osmosis water desalination system, with Keefer providing the expertise on the reverse osmosis unit design and TPK that on the system's power tracking and control. This project has yielded a system with good domestic and international market potential. Adkinson and Associates addressed the design requirements for PV electrical power for remote residences where cooking and heating needs are supplied by other energy sources. EKEG's project was on instrumentation to monitor photovoltaic system operations in extreme Canadian weather conditions. Lenbrook Industries in association with United Power Corporation undertook a project on photovoltaic-powered highway lighting in British Columbia.

Details of all these projects are given in the 1984 edition of the SEP Contract Registry.

Overall, the directed approach of the third Small PV Power Systems RFP was judged to be very successful. A fourth RFP was planned for 1985 with the proposed priority topic to be PV-diesel hybrid systems. PV-diesel hybrids are considered to be of great interest by the Canadian Coast Guard for some larger remote installations of warning beacons, and a recent study carried out by the Con-Serve Group for the Ontario Ministry of Energy suggests that such systems should be cost-effective for remote village power in Canada by 1990.

2.5 Performance Evaluation

a) Introduction

From the beginning of the SEP in NRC, the importance of the direct involvement of the Division of Energy with some projects was recognized in order to

i) attract technically good staff;
ii) maintain and increase their technical knowledge.

The first technical project to be done within the SEP PV Sub-program was defined in early 1981: a systems modelling and simulation activity. A Visiting Research Officer was invited to spend the summer of 1981 at SEP to start this activity. In late 1982, a new position was staffed to build up the activity further. Subsequently a number of summer and co-op students have also participated in this work.

Projects such as the Atikokan installation (see sub-section 1.6) helped quantify the need for in-house work on system performance studies and define new projects. For the last two years, the SEP PV Sub-program staff has participated actively in the monitoring of PV systems performance by defining the monitoring programs, supplying the monitoring equipment, analyzing data and, in some cases, installing and maintaining the data acquisition equipment.

As well as simulation studies and monitored field trials, controlled systems experiments were needed. Working systems which are installed for specific field trials can only be monitored, not studied. The PV array output can only be measured at the voltage determined by the system at the existing insolation and temperature. The systems often include battery storage whose properties depend strongly on temperature as well as age and charge/discharge history. Further, the load on the system usually varies with time. It is a complex task to understand the interaction of the components of the system as a function of available insolation, temperature and time, and the task is frequently made more difficult by the lack of adequate information on component performance in the Canadian environment. A further limitation can be imposed if the system is a remotely located one in which case only very limited data may be collected because of power restrictions and lack of data storage capability.

In the Spring of 1984, these considerations led to a proposal for an NRC in-house photovoltaic systems experimental laboratory to complement the modelling and simulation activity and the monitoring of working systems. In June 1984, an agreement was reached between the Divisions of Energy and Electrical Engineering to establish such a laboratory jointly staffed by the two Divisions.

b) Simulation and Modelling

The existing computer modelling programs for PV systems, available to the public, generally fall into one of two widely different categories, namely, i) detailed hour-by-hour simulation packages for use on a main-frame machine which require extensive environmental and load input data;

ii) simplified sizing tools written for microcomputers which rely heavily on phenomenological correlation relations between environment parameters, thus employing a minimal amount of input data.

From this background situation, the in-house work commenced with two objectives in mind, firstly, to make available on the NRC main-frame computer a detailed hour-by-hour simulation package which could model a variety of PV power systems and readily accept Environment Canada weather data and, secondly, to examine individually the numerous assumptions in the simplistic methods with a view to improving their performance by removing the worst inaccuracies by making them slightly more complex.

The University of Wisconsin's TRNSYS package was chosen as the starting point in the hour-by-hour simulation work. This program has had widespread use in studying solar thermal systems including work at NRC, its well designed overall structure is readily understood, and good documentation has evolved for its use. However, it lacked a sub-routine to model a PV module/array, containing only one for a combined PV/thermal collector, and so the first task was to produce this sub-routine. The approach used was to fit the I-V curve of the given module/array measured under standard conditions to a phenomenological model which could then be used to predict the module/array characteristics under other conditions. This task was completed satisfactorily such that the finalized model represents an improvement over previously published procedures.

The work then moved on to experimentation with the overall package of PV systems which involved the incorporation of sub-routines modelling electric motors, water pumps and storage batteries. During the course of this work, it became apparent that the interpolation procedures automatically invoked during the running of TRNSYS were unnecessary in the case of PV systems and, furthermore, occasionally introduced needless inaccuracies. In view of this, a simpler overall structure was coded but all the component sub-routines were kept TRNSYS-compatible. The whole amended package is now available with running procedures which accept standard AES weather data tapes and can be used to simulate the performance of a variety of PV systems such as water pumps and stand-alone residential units under Canadian conditions.

A major shortcoming of this package, and all similar ones, is the poor model employed for lead-acid storage batteries. Beyond the fact that such a complex electrochemical system is difficult to model lies the basic problem of lack of information on charge/discharge characteristics as a function of temperature, charging rate and battery age. Since the storage battery performance frequently determines the success of PV systems in remote locations in cold climates, it was planned to undertake a program of measurement of battery characteristics in the immediate future. At the time of the abandonment of the Program, a Post-Doctorate Fellow had been offered an appointment to carry out this study.

Work on the second objective was less advanced. However, a copy of the most common simple design tool, PV F-Chart, another product of the University of Wisconsin, had been installed in-house on an Apple II microcomputer. The sequence of approximations and correlations used to simulate hour-by-hour radiation values on the array slope through the year from just a dozen monthly-average daily radiation values on the horizontal plane have been identified and their accuracy examined for a number of Canadian locations. Improved correlation relations for northern latitudes have been derived in some instances.

c) Data Acquisition from Operating Systems

In order to validate the systems simulation computer programs, data from operational systems are required. To obtain such information, a number of systems were identified for monitoring on a continuous basis. Firstly, the SEP PV Sub-Program supplied the data acquisition equipment for the 4 kW system at the Technical University of Nova Scotia (TUNS) and in return was receiving regularly system data. Additionally, the PV Sub-Program staff of NRC have designed, developed and installed data acquisition equipment to monitor Ontario Hydro's grid-connected PV system at the Kortright Conservation Centre, near Toronto, and Transport Canada's beacon warning system at the Ottawa International Airport.

The TUNS system consists of ninety-six 40 watt PV modules and forty-eight 500 ampere-hour batteries along with an inverter which can be operated in either phase-locked or stand-alone mode. This permits experiments to be conducted to study the operation of the system with a residential load pattern operating either in a grid-connected mode or a stand-alone mode utilizing the battery storage.

The Ontario Hydro grid-connected system at Kortright has a 1 kilowatt PV array which supplies a portion of the power requirement of the curator's residence. The data acquisition system monitors a complete set of current, voltage, power, irradiance and temperature values, allowing a thorough examination of sub-system efficiencies, power availability and utilization factor.

The Transport Canada warning beacon is a 500 watt system operating at 24 volts D.C. The system consists of 16 PV modules, 24 storage batteries, a voltage regulator and the lamp. This system is of great interest to NRC as a representative example of many such "simple" systems already existing in Canada and expected to form the primary Canadian PV market for several years. Consequently it is anticipated that the operational data will result in the establishment of a more accurate systems model enabling present and future users to understand the operation of their systems more fully. It should help to design systems with higher reliability and/or lower costs. The lower costs should come about through optimizing the system sizing to reduce the probability of failure to the desired level. (The present practice is to select an oversizing factor by rule of thumb.)

At the time of the abandonment of NRC's SEP program, discussions were taking place with the Water Survey of Canada and the Defence Research Establishment, Ottawa, in the area of PV system operation in the Canadian environment. The PV Sub-program staff were preparing to do further system monitoring, system modelling and battery storage evaluation in conjunction with the PV programs of these two organizations.

d) Photovoltaic Systems Experimental Facility

In May 1984, the SEP PV Sub-program staff made a proposal to the management of the Divisions of Energy and Electrical Engineering for the installation of a photovoltaic laboratory for system level experiments. The objective was to provide know-how and data on the characterization and performance of PV systems, their sub-systems and components in support of industrial research and to enhance NRC's capability to competently advise industry and users including other governmental agencies in all aspects of photovoltaic technology. Very few studies are being done worldwide on PV applications in cold climates and northern latitudes, a topic which the SEP staff recognized as an important aspect for a Canadian PV program.

The proposal was accepted and it was agreed that a Photovoltaic Systems Experimental Facility (PVSEF) be installed as a joint project of the Divisions of Energy and Electrical Engineering. A Steering Committee, headed by the Directors of the two Divisions, was established to oversee the implementation and operation. The detailed layout of the laboratory, cost estimates, manpower requirements, task definitions and the modus operandi were discussed, formulated and approved during 1984. The construction of the outside installations - a test cabin, battery hut, and the solar arrays - were planned to be completed by July 1985. However, the project was stopped in November 1984 prior to the commencement of actual site work.

2.6 Testing and Standards

a) Testing

The photovoltaic module test capability at the NRC National Solar Test Facility has been developed further through contracts placed with ORF. A power supply was purchased and software was written to permit the automatic measurement of PV module electrical characteristics and the subsequent storage of the data in the NSTF Xycom computer. Plotting routines were also written to produce hard copy displays. A spectrophotometer was constructed to make spectral response measurements of PV cells used in the reference cell method of PV module testing. Testing methodologies and equipment were developed for environmental tests such as the hail impact test, the torsion test and the temperature cycle test. A round-robin comparison of test results between ORF and the Jet Propulsion Laboratory (JPL), Pasadena, California showed agreement on single crystal cell modules to within 2%.

With the developed equipment several series of tests have been performed on production modules. With some minor exceptions ORF now has the capability to test modules to a) the Canadian Coast Guard Specification MA 2055, b) the Canadian Standards Association (CSA) standard on PV modules F380, and c) the JPL Test Specification 5101-161.

In conjunction with the NRC PV sub-program initiative to promote a Canadian capability in PV-powered water pump development, ORF was awarded a contract to extend their module testing facility to permit indoor and outdoor testing of PV-powered pumping systems. This development is nearly completed.

b) Standards

NRC provided representation on the two CSA PV Technical Committees which were assigned the tasks of preparing standards for PV modules and for PV systems respectively. The Preliminary Standard F380-1984 on Photovoltaic Modules was issued in October 1984. This standard describes the requirements for the measurement of the performance of terrestial PV power modules. The committee on PV systems is close to completing Preliminary Standard F381 which deals with power conditioning aspects of PV systems.

The NRC sub-program provided support for Canadian representation on the International Electrotechnical Commission (IEC) Technical Committee on PV Standards (designated TC82). Three working groups were formed by the committee on a) glossary of terms; b) modules; and c) systems. The glossary group, chaired by Canada, has published a preliminary list of terms for circulation to the other two groups. The modules group is now circulating a number of documents which it has approved and which should form the basis for a modules standard. Finally, the systems group intends to issue individual standards for components such as storage, arrays, power conditioners, and utility interface subsystems. A systems description entitled "Guide to PV Systems" is now being prepared.

Initially, Canada was not a participant in the Photovoltaic Solar Energy Project of the Summit Working Group on Technology, Growth and Employment which was set up by the Heads of State at the Versailles Summit in 1982. However, after an initiative by the President of NRC, a member of the NRC sub-program staff attended as an observer the 2nd Experts' Meeting in Ispra (January, 1984) and then the 2nd Joint Coordination Meeting in Tokyo (November, 1984). Additionally, Canada is now participating in a programme of round-robin testing of photovoltaic cells.

2.7 Other Canadian Activities

The photovoltaic device research projects of several groups have been supported by SEP, but it should be remembered that the Division of Energy was only one of several funding agencies supporting work on this topic. Many other research groups have been funded by NSERC under both their Operating Grants and the Strategic Grants programs; and a few projects have been supported by the FCAC of Québec and by IRAP of NRC.

Similarly, the activities of the Canadian PV industry are not fully represented by the projects described in the preceding sections. Other work has been funded by DRIE, the Ontario Ministry of Energy, and EMR or has been undertaken by the companies themselves in order to respond to requests for quotations on PV equipment. Lenbrook Engineering, which markets SOLAREX modules in Canada, designed and installed a photovoltaic system for a ranger's cabin in Quetico Park for the Ontario Ministries of Energy and Natural Resources. TPK Solar developed and is successfully marketing a laminator for modules and has recently announced sales of cell and module production lines to India and China. Mechron Engineering, working with the Canadian Coast Guard, has developed a cold start diesel for use in PV hybrid systems.

Further, several companies, for example, Sun-Direct Energy Systems of Colinton, Alberta, Tele-Radio Systems of Woodbridge, Total North Communications Ltd. of Whitehorse and Westronic Engineering Sales Ltd. of Vancouver, supply photovoltaic components as consumer items for power systems. Numerous consulting engineering firms have been involved in studies on photovoltaics: two recent studies are the Techno-Economic Research Unit study on Canadian PV markets and the Con-Serve study on Intermediate PV Systems, both commissioned by the Ontario Ministry of Energy. Two new companies, Solarpac Energy Systems Inc. of Mississauga, Ontario and Synercan Energy Systems Ltd. of Willowdale, Ontario were incorporated in 1984 intending to manufacture PV modules and to work on systems design respectively.

Government agencies are by far the largest users of PV power systems in Canada. Early studies of use include those of Alberta Government Telephones and CP Rail, as well as the Canadian Coast Guard. Some of this early work was reported on at the PV Seminar held at NRC in October 1979[1]. The Canadian Coast Guard's initial work has led to a major program of conversion of remote beacons to PV power and proposals for PV-diesel hybrid power systems for lighthouses are under discussion. The Water Survey of Canada intends to convert several hundred water level monitors to PV power. DREO, the RCMP, and Transport Canada have all experimented with PV power in remote locations. A major program was announced in 1984 by CIDA to spend in the order of $15M on photovoltaic powered water pumping systems for the Sahel region of Africa.

The proceedings of a Photovoltaics Symposium[9], jointly hosted by NRC and Ontario Ministry of Energy in September 1984, give a further perspective of the extent of PV activity in Canada at that time and, in particular, contain many papers on the more applied work.

Certain kinds of work needed, not only by industry but also by government groups using photovoltaic systems, were not suitable to be performed by industry either because the payback was too long or because the project required a different mix of disciplines. For similar reasons, this work could not be done by the agencies needing the photovoltaic systems.

Therefore a joint project between the Divisions of Electrical Engineering and Energy of NRC had been set up under the leadership of one of the Energy Division PV Sub-program staff to establish a photovoltaic systems laboratory to be jointly staffed and utilized by the two Divisions.

It was envisaged that the photovoltaic system laboratory, the PVSEF, was to act as the focus of this work and permit the detailed study of systems and components in the Canadian environment. The PVSEF would include the capability to characterize PV cells as this was a service often requested of NRC by researchers. Indeed, equipment for this activity was already on order prior to November 1984. Another topic under discussion for future in-house work was solar cell research on the more applied aspects such as the achievement in production of high efficiency and good quality control.

3. Perspective and Recommendations

3.1 Summary of Status

The direct conversion of the energy contained in sunlight into electricity for terrestrial use has been studied worldwide with great effort and success during the last few decades. Technologies for the production of solar cells, modules and systems have been and continue to be developed.

The extent of development of a Canadian photovoltaic capability has been due largely to the Solar Energy Program at NRC. Over the past 5 years of its existence, it has not only funded R&D work for basic materials research of photovoltaics, but also applied research for cell and module production technology through to system design, performance monitoring and modelling. Several Canadian university research groups now exist which are performing world class research on PV materials and cells. Three Canadian companies are presently manufacturing photovoltaic modules. In fact, one company has won two large export contracts from India and China for solar cell and module production lines. The systems research funding has resulted in the production of marketable photovoltaic systems such as lighting, water pumping and water desalination systems. Photovoltaic system design capability now exists in several Canadian companies.

3.2 Rationale for Future Canadian PV Activity

Because Canada, as a northern country, has a great variation in available sunlight from winter to summer, it is not expected that photovoltaic power will be competitive with grid power in the near term or medium term. However, PV systems can be an important power source for northern and remote locations. Snow in winter increases the collected energy significantly by reflection; the near vertical mounting of PV modules decreases dust accumulation and consequent maintenance costs or loss of power, over that found in more southerly locations; and the much colder winter temperatures lead to an increase in power conversion efficiency.

Many Canadian agencies are successfully using PV systems at this time to supply power for remote applications because such systems are cost-effective and more reliable than other power sources. However, in most cases, little effort is spent to assess the PV systems installed. The result often is a system that works but is not of optimum design, and consequently is more expensive than it need be. In addition, poor communication between users results in inefficient utilization of information gained from PV system experience. Engineering standards and practices are not yet fully developed. The impact of Canadian climatic conditions on system design and performance is not fully understood; and design, modelling and monitoring information require better coordination to increase its usefulness to Canadian users. There is therefore a need in Canada for a systems group working in PV. The continuity required of such a group implies stability in funding and manpower. Neither the Canadian companies nor the Canadian user agencies engaged in PV activity consider it their duty to study systems design optimization nor have they the inter-disciplinary teams to do the work.

Other factors to be considered are future Canadian applications of PV and foreign markets. Foreign markets exist now and will grow rapidly in the future as PV costs come down. In the medium term, PV systems may be economical to power remote dwellings and villages. The reduction in costs that these events depend on will come about as a result of developments in PV cell and module technology not necessarily taking place in Canada. Consequently it is important that these developments be monitored on a continuing basis in order that government and industry be made aware of new opportunities.

Research on PV materials, cells and modules has been funded by NSERC, IRAP of NRC and provincial governments in the past. Assuming that this practice continues in the future, the same person or group responsible for observing the world PV activities should also be responsible for coordinating Canadian activities in the material, cell and module research areas. The coordination would be limited to determining the relevance of the Canadian research in these areas and to making the Canadian researchers aware of world developments in PV.

Many of the semiconductor materials of interest for PV devices, and many of the thin film deposition technologies, are also being studied intensively for semiconductor electronics. All of the measurement techniques are of importance for both PV and other semiconductor devices. NRC could maintain the expertise to advise NSERC and IRAP on PV device proposals as well as to provide technical assistance to industry.

Canadian usage of PV has grown rapidly in the last ten years and is expected to continue growing. A large portion of the modules being used in Canada are foreign made due to lower costs and tested reliability. This trend will continue until significant funding of the Canadian PV industry occurs. That may not occur before there is a significant reduction in PV cell cost. However, there will continue to be a demand for PV systems which means opportunities for Canadian PV system design companies.

3.3 Recommendations

It is recommended that material device and module work be continued primarily in universities and industry supported by NSERC and IRAP programs. An observer/coordinator should be assigned the task of providing a current status of world PV activities for government and industry as well as act as coordinator for Canadian research on PV related topics as defined in Section 2.

The development of system components like modules, inverters, controllers, or balance of systems items should be done primarily in industry or in universities.

A systems related activity should, however, be established with continuing government support. The system related work performed by the group should concentrate on the systems aspect in the Canadian environment, i.e. the inter-relation of environment, power source, energy storage, load management and system control. The work should be carried out through system modelling and monitoring, design and lab experiments.

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6 "Contract Registry, 1983-84", Solar Energy Program July 1984, NRCC No. 23526.

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8 "Contract Directory", Solar Energy Program June 1983, NRCC No. 21381

9 "Proceedings: Symposium on Photovoltaics" held in Ottawa, September 6 and 7, 1984.

APPENDIX "1"

REQUESTS FOR PROPOSALS

Spring 1977:1st RFP for PV device work,File #7-0001 (16 responses, 6 contracts).

Spring 1978:2nd RFP for PV device work, " #8-0010 (14 responses, 5 contracts).

Spring 1979:Canadian Market Survey RFP, " #8-2678 (responses, 1 contract).

Spring 1980:Small PV Power Systems I, " #9-2645 (11 responses, 3 contracts).

Autumn 1980:a-Si RFP, " #0-2602 (7 responses, 1 contract).

Summer 1981:Newer Materials & Devices I, " #1-2613 (14 responses, 3 contracts).

Winter 1981:Small PV Power Systems II, " #1-2658 (15 responses, 1 contract).

Spring 1982:Newer Materials & Devices II, " #1-2698 (13 responses, 5 contracts).

Spring 1983:Newer Materials & Devices III," #2-2722 (10 responses, 5 contracts).

Summer 1983:Small PV Power Systems III, " #3-0019 (19 responses, 8 contracts).

Spring 1984:Newer Materials & Devices IV, " #3-3021 (9 responses, 2 contracts - 8 selected for support).

APPENDIX "2"

PV Funding Levels

YEAR	BUDGET +
1977-78	$ 150K
1978-79	$ 650K
1979-80	$ 650K
1980-81	$ 900K
1981-82	$1100K
1982-83	$1500K
1983-84	$1800K
1984-85	$2400K
1985-86 (proposed)	$2900K

+ These numbers are subprogram R&D budget values, i.e. they do not include overhead, DSS charges, etc.

APPENDIX "3"

5-year plan Photovoltaics, November 26, 1980

	80/81	81/82	82/83	83/84	84/85	85/86
A. Long term R&D on materials and devices	$400K	$500K	$550K	$750K	$850K	$900K
B. Short term R&D on cells and encapsulation	290	425	725	975	1250	1500
C. Power systems components	90	350	600	700	750	750
D. Systems trials - proof of concept experiments	40	400	600	600	500	500
E. Testing - facilities, monitoring methods, standards	-	100	250	75	75	75
F. Information - resource assessment, technical studies etc.	80	100	100	100	100	100
G. New initiatives	-	50	125	150	175	200
	$900K	$1925K	$2950K	$3350K	$3700K	$4025K

APPENDIX "4"

Proposed budget by topic - 85/86

A.	Research on Materials/Devices	$1050K
B.	Cell/Module Processing Technologies	$ 600K
C.	Systems/Component Development	$ 500K
D.	Systems Performance Evaluation	$ 500K
E.	Test Methods and Standards	$ 150K
F.	Other - Feasibility and Technical Information Studies	$ 100K
		$2900K